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Some Recent Studies of Coal Combustion and Gasification

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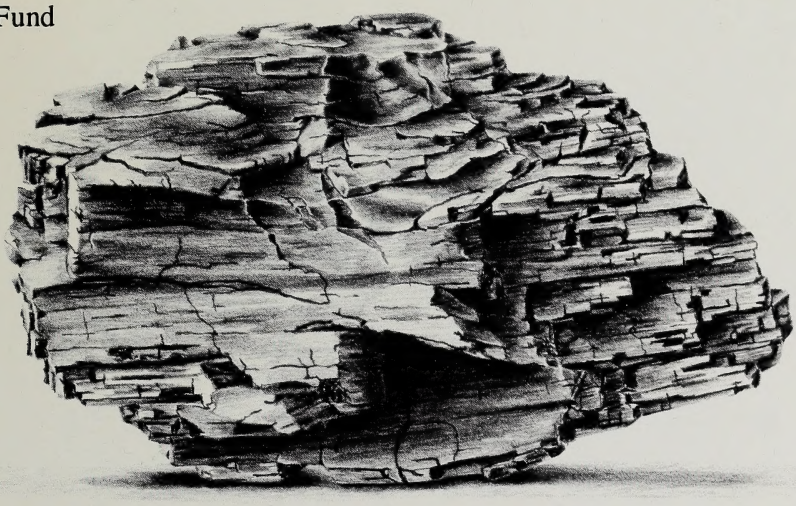
Research Fund



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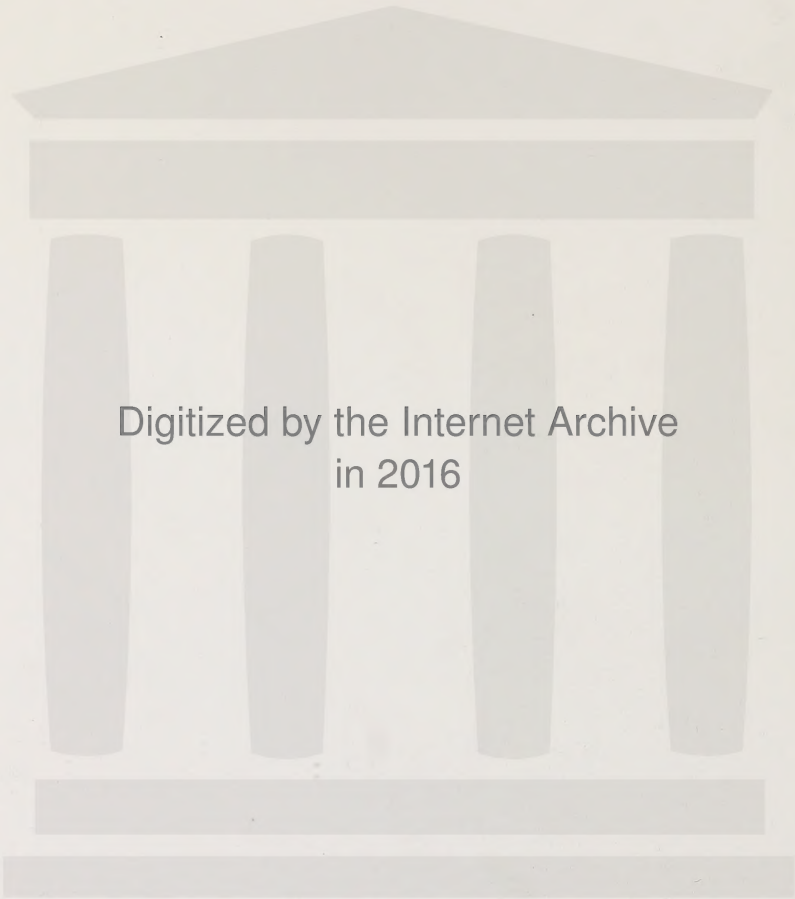
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ISBN 0-86499-854-6

Pub. No. T/252

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Foreword

Beginning in 1976, numerous projects were initiated in Alberta by industry and academic research institutions to help make better use of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rested with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities focused primarily on coal, energy conservation and renewable energy, and conventional energy resources. In 1988/89, a hydrogen research component was added.

Administration for the A/CERRF program was provided by staff within the Research and Technology Branch of Alberta Energy.

In recognition of the importance of coal to Alberta's economy, the Alberta Office of Coal Research and Technology was established in 1984 within Alberta Energy and Natural Resources (now Alberta Energy). Its primary purpose is to encourage the development and application of new technologies related to Alberta coals. The Office provides funding contributions to research and development projects in industry, academic institutions and other research establishments. It also monitors the progress of these projects in an overall program of improving the production, transportation and marketability of Alberta coals.

The A/CERRF program ended on March 31, 1991 and the support it provided has been replaced by funding from the Alberta government.

A series of technology transfer booklets begun in 1986 with A/CERRF support continues to make research results available to industry and others who can use the information.

This service will continue until all A/CERRF projects have been described.

For more information about other publications in the series, please refer to page 19.

Some Recent Studies of Coal Combustion and Gasification

Introduction

Some emerging coal combustion technologies achieve optimum performance from coals having narrowly specified properties. Consequently, coal producers who wish to sell coal to the users of these technologies must be prepared to provide detailed information about the combustion characteristics of their coals. Furthermore, advances in the science of coal combustion make it necessary to test coals for properties other than those revealed by ultimate and proximate analyses. This means new or improved laboratory-scale combustion testing methods must be developed that not only simulate coal burning in thermal plants but, ideally, can minimize the need for the expensive, full-scale combustion tests used in the past.

Another important function of coal combustion research is to encourage coal producers, coal users and manufacturers of coal-burning equipment to become jointly involved in projects. This can lead to knowledge sharing and the enhancement of technology development in ways that benefit all parties.

With these issues in mind, A/CERRF has provided financial support for approximately 19 coal combustion research projects. Some of these were described in an earlier technology transfer booklet, titled Some Combustion Studies of Alberta Coals.

Some of the knowledge gained from these combustion studies has been applied during investigations of the gasification characteristics of Alberta coals. Also, several studies were performed to obtain detailed information about Integrated Gasification Combined Cycle systems for gasifying coal and producing electricity. Some results of this research have been reported in two technology transfer publications, namely: *Gasification of Western Canadian Coals;* and *Gasification of Alberta Coals.*

Collectively, the combustion and gasification research activities supported by A/CERRF represent the largest components of the clean coal research program of the Alberta Office of Coal Research and Technology. The earlier accomplishments of this program were described in July 1989 in the publication *Development of Clean Coal Technologies for Alberta.*

All combustion and gasification research completed since 1989 is described here.

Combustion Research

International Energy Agency Coal Combustion Science

Annex II of the International Energy Agency Combustion Science Research Program involved fundamental studies and a series of investigations using semi-industrial scale coal burners to advance the science of pulverized coal combustion and minimize adverse environmental effects from the combustion of coal. Facilities of the International Flame Research Foundation (IFRF) at IJmuiden, The Netherlands, were used.

The principal objective was to provide information that can be used to design burners capable of using a wide range of coals and produce flames having acceptable combustion characteristics, while generating few atmospheric pollutants.

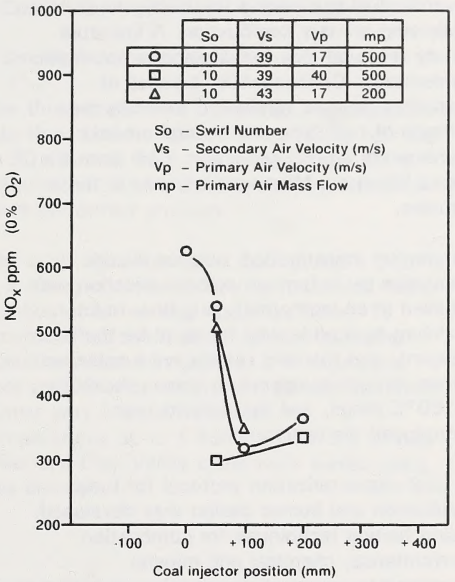
Initially, the Annex II studies were funded jointly by Canada, The Netherlands and the Federal Republic of Germany. Since 1985, the Canadian contribution has been divided among the Canada Centre for Mineral and Energy Technology (CANMET), the Canadian Electrical Association and A/CERRF, as represented by the Alberta Office of Coal Research and Technology. The Office participated on behalf of Alberta coal producers to obtain comparative information on the combustion performance of selected Alberta coals relative to other internationally traded coals.

A second reason for Alberta's participation was to acquire knowledge about the use of low-rank Alberta coals for power generation and other applications.

The research program investigated the following mechanisms: nitrogen oxides (NO_x) formation during pulverized coal combustion and opportunities for their reduction through staged combustion; sulphur oxides (SO_x) formation and reduction by the use of direct sorbent injection; transformation of mineral matter during combustion in relation to combustion system slagging, fouling and fly ash emissions; and combustion of various types of coal from several sources. The study also developed methods of predicting flame characteristics.

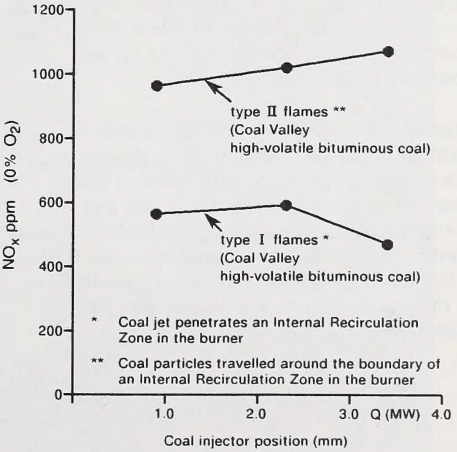
Two air-staging methods were studied extensively: an aerodynamically air-staged burner (AASB) and an air-staged precombustor burner (ASPB). All experiments with these burners were conducted with high-volatile and medium-volatile bituminous coals, including some from the Coal Valley Mine of Alberta to study the effect of operating at scales of 1, 2.5 and 4 MW. Studies showed that both coal quality and burner scale affected the level of NO_x emissions. NO_x levels decreased with increasing burner size. Also, a trade-off between NO_x reduction and carbon burnout occurred. The best performance for the AASB was a NO_x concentration of 240 parts per million (ppm) in air emissions, with a 98.5 per cent burnout. This occurred in the absence of excess oxygen. In the case of the ASPB, NO_x emissions were 250 ppm at a carbon burnout of 98.5 per cent.

Effect of Coal Injector Position on NO_x Emissions



(Source: NO_x Reduction and Burnout Optimisation Using Aerodynamic Air Staging and Air Staged Precombustors, Smart, J. and R. Weber, International Flame Research Foundation, 1987.)

Effect of Burner Scale on NO_x for Aerodynamically Air Staged Burner



(Source: The Effect of Scale on the Performance of the Aerodynamically Air Staged Burner, Smart, J.P., W.L. van de Kamp and M.E. Morgan, International Flame Research Foundation, 1989.)

A second approach to NO_x reduction was reburning or fuel staging. This involved using overfire fuel to create a fuel-rich zone following primary combustion. A literature study revealed that fuel staging is not well understood. Consequently, a series of experiments was conducted to study the effects of coal type and several process parameters on NO_x reduction. Coal from the Obed Mountain Mine was included in these studies.

In another investigation, sulphur dioxide reduction by in-furnace sorbent injection was studied in an isothermal, plug-flow reactor. Calcium hydroxide was found to be the best reagent, and the best results were achieved when furnace temperature was in the 900-1100°C range, and the sorbent was introduced via tertiary air.

A coal characterization protocol for fuels evaluation and burner design was developed, using testing techniques for combustion performance, chemical and mineral composition, maceral composition and reactivity. Coals from the Highvale and Coal Valley mines were included in these studies. Char combustion and pyrolysis behaviour were characterized, and simple models were created to predict the performance of various coals. These models, which included predictions about the heat content of volatile matter, carbon burnout and the abundance of NO_x-forming species, were used to rank the combustion performance of coals for any specified combustion environment.

Algorithms used to simulate and predict turbulent fluid flow were used to develop flame models for isothermal, swirling flows near burner nozzles. Flow fields and gas temperatures can be modelled reliably, but predictions about gas composition need further refinement. Achieving accuracy of predictions in the near-burner field was the primary objective of these studies.

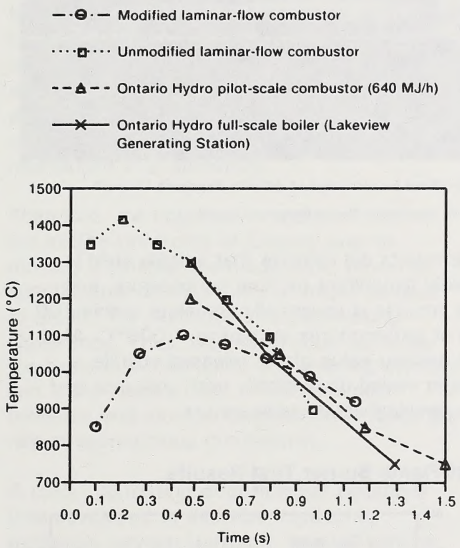
Combustion Properties of Alberta Coals and Chars

It is well known that some coals burn faster and more completely in a variety of combustors, but the reasons for this behaviour remain unclear. To obtain a better understanding of coal combustion phenomena, a project was initiated by the Alberta Research Council (ARC) with the objective of upgrading a combustor and using it to study the char combustion rates of two Alberta coals. Another objective of the project was to create a conceptual and numerical model of single-particle combustion.

An existing laminar-flow combustor having a feed rate of 3 kg/h was modified to allow control of the temperature profile in the combustor, and a swirl burner was installed to achieve the higher temperatures and carbon burnout that are more typical of commercial-scale boilers. In testing the upgraded combustor using a high-volatile bituminous coal, it was found that the flame temperature could be increased from 1 150°C to 1 500°C, and carbon burnout was raised from 90 per cent to 97 per cent. This made the device capable of better simulating full-scale utility boilers.

A mathematical model was developed to analyse the reaction of a single char particle in combustion or gasification atmospheres. The model examined the heat and mass transfer, and chemical reactions occurring in the boundary layer around a reacting char particle. The model successfully predicted the particle temperatures and conversions for two Alberta coal chars under one set of combustion conditions. It also showed that combustion of carbon monoxide to carbon dioxide in the boundary layer significantly affected particle temperature. This effect should be taken into account when calculating char reaction kinetics from experimental data.

Comparison of Furnace Time / Temperature Profiles



(Source: Chambers, A. K., B. Ozum, M. Malychuk, R. Zacharkiw and D. Ungarian, Combustion Properties of Alberta Coals and Chars, Alberta Research Council, 1990.)

Devolatilization Properties of Alberta Coals

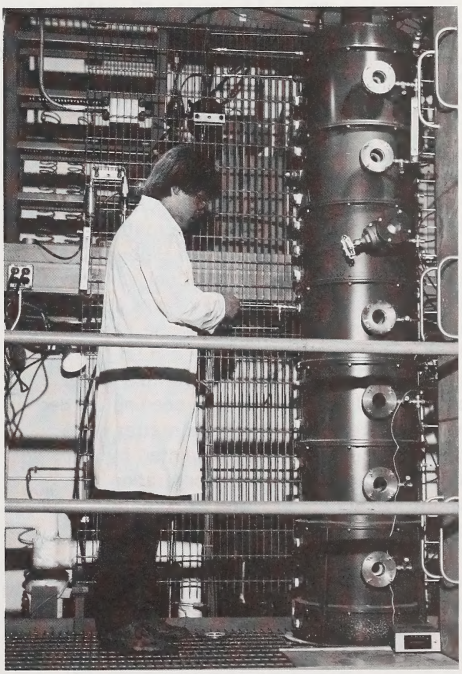
When heated, coal releases part of its mass as tars and gases in a process called devolatilization. This process, which is dependent on coal type, particle size, process conditions and final temperature, is the first step in the combustion or gasification of coal. Thus, in combustion processes, devolatilization determines the quantity, composition and heating value of the volatiles that affect flame stability. In gasification, the reactivity of the remaining solid char, and subsequent production of NO_x and SO_x, are also affected by devolatilization.

Although studies have been made of devolatilization behaviour under low rates of heating, little is known about it under the high heating rates experienced in entrained-flow combustion and gasification processes. Therefore, during 1989, an investigation was carried out at the Alberta Research Council to develop techniques for evaluating the devolatilization properties of the following three Alberta coals:

- Highvale subbituminous;
- Coal Valley high-volatile bituminous; and
- Smoky River low-volatile bituminous.

The three coals were pulverized and separated into three size fractions corresponding to: 106 to 90 microns; 75 to 63 microns; and 53 to 45 microns. Ultimate and proximate analyses were performed on each.

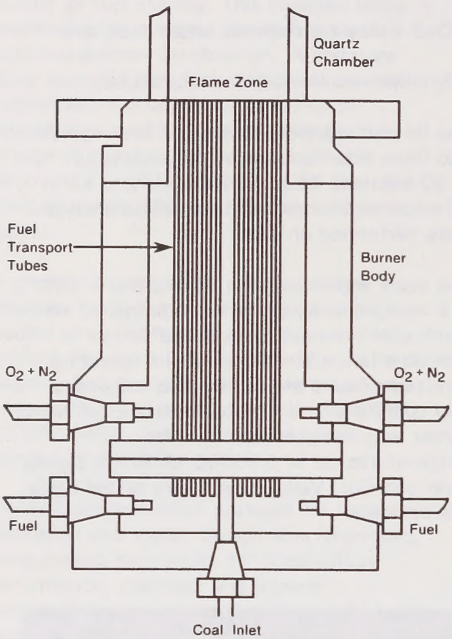
The coals were heated at 800°C and 1 000°C in a nitrogen atmosphere in an entrained flow combustor for various residence times. To provide a better simulation of the operating conditions found in gasifiers and large-scale coal combustors, a high-temperature flat-flame burner was designed and built for temperatures up to 1 550°C. Both the Smoky River and Coal Valley coals were tested using this device.



A laminar-flow combustor used at Alberta Research Council was modified to simulate commercial-scale burners.

(Photo courtesy of Alberta Research Council)

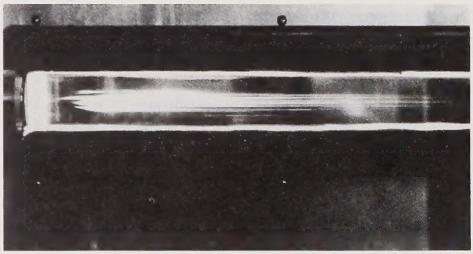
Flat-Flame Burner Body Detail



(Source: Malychuk, M., A. K. Chambers and D. E. Ungarian, Devolatilization Properties of Selected Alberta Coals, Alberta Research Council, 1989.)

The results from using the entrained flow combustor showed that volatile loss was only 10 per cent for all three coals at 800°C. At 1 000°C, the yield of volatile matter increased to 30 per cent for the Highvale coal, more than 40 per cent for the Coal Valley coal and 25 per cent for the Smoky River coal. At the higher temperatures used in the flat-flame burner, the Coal Valley sample lost up to 70 per cent of its mass, while the Smoky River coal produced volatile yields exceeding 30 per cent. These releases of volatile matter were approximately twice those predicted by proximate analysis, thus demonstrating the inherent inaccuracy of using proximate analysis as an indicator of coal volatility.

None of the size fractions used in this work had any noticeable influence on the results, but the sample sizes, combined with gas temperature measurement and char nitrogen analysis, contributed to scatter in the results. This made it impractical to use results from these tests to develop mathematical models of the devolatilization process.

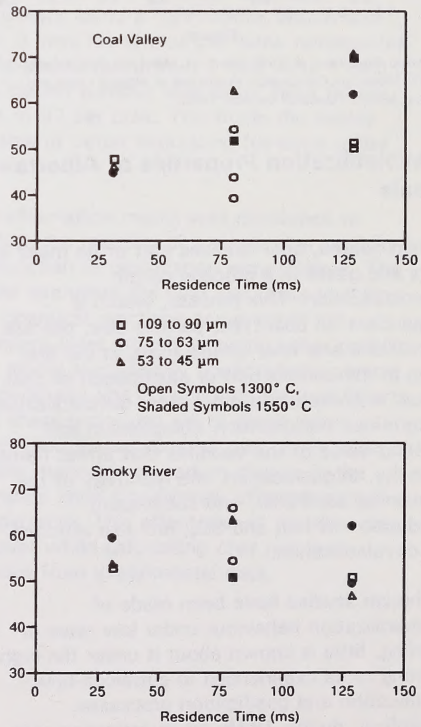


Flat-flame burner used at Alberta Research Council.

(Photo courtesy of Alberta Research Council)

The results did indicate that volatile yield is mainly dependent on final temperature, and the process is essentially complete within 100 ms at temperatures exceeding 1 000°C. Also, the heating value of the released volatile matter varied dramatically with coal rank and the devolatilization temperature.

Flat-Flame Burner Test Results



(Source: Malychuk, M., A. K. Chambers and D. E. Ungarian, Devolatilization Properties of Selected Alberta Coals, Alberta Research Council, 1989.)

A Thermodynamic Model for the Spontaneous Combustion of Coal

In recent years, some progress has been made in understanding the causes of spontaneous combustion, and in characterizing coals according to their susceptibility to this phenomenon. However, all the conditions existing in a coal storage facility cannot be reproduced in a laboratory.

Therefore, the objective of a project carried out at The University of Calgary was to develop a reliable, thermodynamic model of spontaneous combustion that might be used to predict the likelihood of a self-heating occurrence. Thus, the model could serve as the basis of a monitoring and warning system, and could also be used to optimize coal transport and storage conditions to reduce the risk of spontaneous combustion.

A model consisting of differential equations was developed to describe exothermic oxidation, oxygen transport, heat of wetting, heat of evaporation, moisture transport and decomposition of peroxides above 70°C. When compared with the results of experimental tests, it was found that the model made predictions about spontaneous combustion that were accurate within a few per cent of the actual experiments.

The research team made seven recommendations to reduce the potential for spontaneous combustion occurring in a coal stockpile. They were:

- to prevent the process of exothermic water sorption, operators should avoid storing coal that has a moisture content below its equilibrium value;
- operators should not suddenly remove thick layers from stockpiles;
- decrease stockpile porosity from 20 to 10 per cent to decrease the maximum temperature in a stockpile by 20°C to 40°C, and lower energy losses by approximately 50 per cent during the initial period of storage;
- to reduce oxygen access, compact the coal rather than decrease the oxidation rate by using surfactants or coatings;
- perform calorimetric experiments on water desorption and peroxides decomposition to provide useful information for the model calculations;
- perform experiments on water chemisorption and desorption using large samples of coal (10 to 20 kg, at least), instead of using 20- to 100-g samples as done now; and
- perform a cost analysis on the storage of coal in large versus small stockpiles.

Sources of Ash Under Controlled Conditions

A travel grant was awarded to Dr. R.C. Joshi of The University of Calgary for a visit to the International Flame Research Foundation (IFRF) at IJmuiden, The Netherlands. The purpose was to investigate the possibility of modifying coal ashes and to determine the sources of variability in fly ash quality. The visit lasted one month and included attendance at two related meetings and conferences.

The outcome was a proposal submitted to IFRF to study the use of modified Alberta coal ash as a cementatious material for construction or as a replacement for cement in concrete in greater quantities than at present. Also, the study would address the production of specification ash to allow its use in cement concrete without any effect on the air entrainment qualities of concrete.

Some samples of ash routinely collected by IFRF staff were collected for fundamental studies, such as by X-ray and Scanning Electron Microscopic (SEM) analyses. X-ray, SEM and Thermogravimetric analyses were performed on coal-combustion residue samples provided by IFRF. Results of these laboratory studies suggested that temperature and residence time affect the properties of these residues.

Gasification Research

Background

In 1987, a consortium[1] of sponsors, headed by TransAlta Utilities Corporation of Calgary, funded an investigation of coal gasification technologies and applications. This included determining the potential for using Alberta coal in existing or emerging systems.

The study concluded that Integrated Gasification Combined Cycle (IGCC) systems now under development are demonstrating several advantages over current, coal-fired thermal technology for electricity generation.

In particular, IGCC is considered the front runner of various proposed "clean coal" technologies intended to produce substantially lower levels of air emissions than do conventional, thermal, electricity-generating systems.

Although experience with large-scale IGCC systems is limited, all indications suggest they produce considerably lower NO_x and SO_x emissions than do conventional coal combustion facilities. Also, particulates are reduced significantly in comparison with conventional thermal plants. In addition, IGCC plants have higher thermal efficiencies than coal combustion plants, leading to lower carbon dioxide emissions.

Therefore, it was recommended that Alberta coal producers and researchers should become actively involved in IGCC developments. Subsequently, the Canadian Coal Gasification Technical Committee (since renamed Canadian Gasification R&D Steering Committee[2]) was formed to oversee and fund coal gasification projects comprising a multi-year research program.

[1]The consortium comprised: TransAlta Utilities Corporation (with Monenco Consultants Limited as the principal subcontractor), Esso Resources Canada limited, Alberta Power Limited, Luscar Ltd., Saskatchewan Power Corporation, Atlantic Coal Institute, and the Alberta Office of Coal Research and Technology.

The objectives of this program were:

- to design and build a 100 MW (electrical) prototype IGCC plant in Canada by 1994;
- to establish and standardize coal gasification testing methods for Canadian laboratories; and
- to facilitate performance evaluations of Canadian coals in various coal gasification technologies.

The program was divided into five major elements. They are:

- Technology assessment;
- Coal characterization;
- Exploratory experimentation;
- Engineering systems design; and
- Applications research.

Projects associated with these elements were initiated, and they covered most of the major steps involved in gasification, from preparing coal as feedstock to emission control. Projects supported by members of the Committee are listed in the Appendix.

During 1990, the Committee members agreed that many of the original objectives had been met. Therefore, research priorities were revised as follows:

- evaluate materials;
- model IGCC and gasification processes;
- quantify emissions;
- evaluate the preparation of fuels;
- conduct gasification tests;
- optimize designs; and
- evaluate uses for by-products.

[2]As of December 31, 1990, participants in the Canadian Coal Gasification Technical Committee were: TransAlta Utilities Corporation, Esso Resources Canada Limited, Edmonton Power Limited, Shell Canada Limited, Gulf Canada Corporation, Luscar Ltd., SaskPower, Westar Mining Ltd., Monenco Consultants Limited, Alberta Power Limited, The Coal Association of Canada, Nova Scotia Department of Mines and Energy, Saskatchewan Department of Energy and Mines, CANMET, University of Waterloo, University of British Columbia, and the Alberta Office of Coal Research and Technology, assisted by the Alberta Research Council.

Also in 1990, five coals were shipped to Japan for testing in the airblown gasification process being developed by the Central Research Institute of Electric Power Industry (CRIEPI). Coal from the Obed Mountain Mine was selected for additional testing in the two-tonne a day plant. In separate testing, Coal Valley coal showed promising results when used in both the CRIEPI and HYCOL gasification processes.

Several coals were evaluated in the Dow gasification process, and five coals, including samples from the Highvale and Paintearth mines, were tested at the University of British Columbia. In this pilot-scale, fluidized bed gasifier, sulphur capture occurs simultaneously with gasification. The final report was distributed to project sponsors.

In September 1990, the Committee held a joint meeting with Japanese members of the Canada/Japan Joint Academic Research Program on Finding Efficient Uses for Coal. Several papers were given on recent developments in coal gasification in Japan, and some members of the Committee gave presentations on research that is under way in Canada.

Gasification Properties of Alberta Coals

If an IGCC system is chosen for Alberta, it must be capable of using Alberta coals efficiently. Thus, a project was carried out at the Alberta Research Council in 1987/88 to measure the gasification rates of some Alberta coals in a thermogravimetric analyser at temperatures ranging from 700°C to 900°C. The results were reported in the publication, *Gasification of Alberta Coals.*

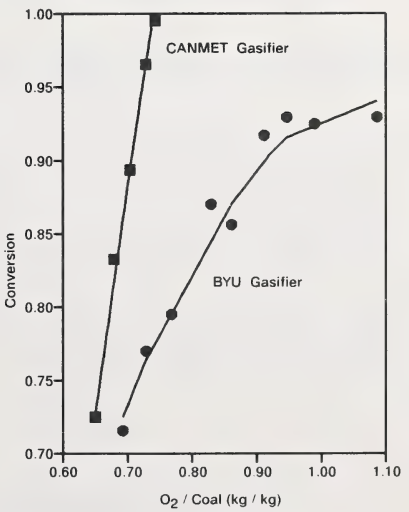
Since that initial investigation, arrangements were made to obtain access by Alberta Research Council staff to a state-of-the-art, entrained-flow, gasification research and development facility at Brigham Young University (BYU) in Utah. Consequently, one ARC staff member was placed at the facility to study gasification of Highvale subbituminous coal at high heating rates.

A range of oxygen-to-coal ratios was investigated, varying from 0.7 to 1.1 kg oxygen/kg of as-received coal. Limestone injection for in situ capture of sulphur was included in these experiments. Some Fourier Transform Infra-red measurements were made of particle temperatures, and gas temperatures and concentrations in the gasification flame.

Solid and gaseous products were analysed for nine gasification experiments. Carbon conversions of up to 95 per cent were observed, and the product gas heating value was in the range of 6.2 to 9.0 MJ/m^3 (165 to 245 BTU/$ft.^3$). Approximately 15 per cent of the sulphur was captured by the limestone when it was injected with the coal at a rate of 0.026 kg of $CaCO_3$ per kg of coal.

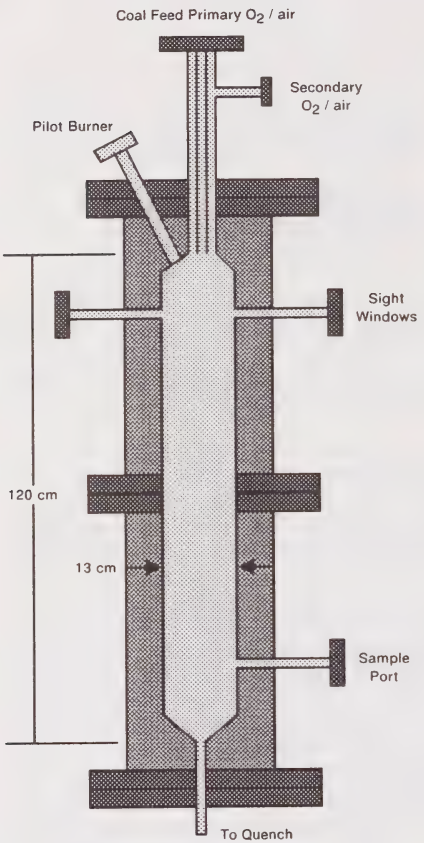
Having acquired experience with the entrained-flow gasifier at BYU, the same ARC staff member subsequently carried out some experiments using an entrained-flow gasifier at the CANMET Bell's Corners laboratories near Ottawa. Five gasification experiments using Highvale coal were completed. Carbon conversion was measured at oxygen-to-coal ratios of 0.65, 0.68, 0.70, 0.73 and 0.74. The highest carbon conversion (0.99) occurred at oxygen-to-coal ratios exceeding 0.7.

Variation of Gasification Carbon Conversion with Oxygen / Coal Ratio, Highvale Coal



(Source: Gasification Properties of Alberta Coals, Kovacik, G., B. Ozum,D.E. Ungarian and A.K. Chambers, Alberta Research Council 1990.)

Canmet Entrained Flow Gasifier

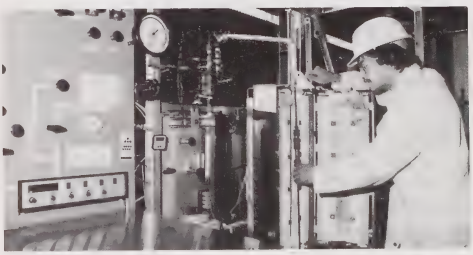


(Source: Gasification Properties of Alberta Coals, Kovacik, G., B. Ozum D.E. Ungarian and A.K. Chambers, Alberta Research Council 1990.)

The sulphur-capture experiments at BYU led to additional work at ARC on sorbent injection, with the objective of developing an inexpensive disposable sorbent for use in removal of pollutant species from gasifiers operating with low-sulphur Alberta coals. This could improve considerably the efficiency and economics of coal gasification processes. The principal pollutants of interest are hydrogen sulphide, carbonyl sulphide and ammonia.

It was reasoned from the BYU studies that sorbent injection would be more effective if the sorbent were injected downstream from, or not directly into, the high-temperature flame zone.

A sorbent injection test unit was built and used to test three potential sorbents: metallurgical red mud, power plant fly ash and water treatment sludge.



Gasifier sorbent unit at Alberta Research Council.

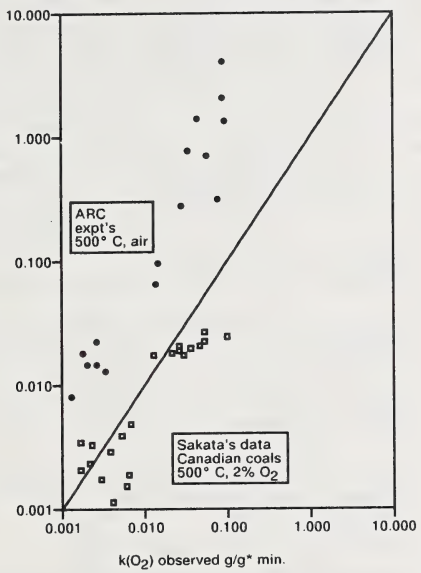
(Photo courtesy of Alberta Research Council)

These experimental observations with water treatment sludge were supported by an evaluation of existing gasification data for equilibrium prediction of sulphur capture when limestone is used as a sorbent. Using F*A*C*T software developed at the University of Montreal, it was calculated that 95 per cent of the sulphur present in the gas resulting from the gasification of Highvale coal could be captured when water treatment sludge is used as a sorbent.

Gasification Testing Protocol

Concurrent with the study at Brigham Young University, a gasification testing protocol was developed for the Canadian Gasification R&D Steering Committee. This was done in co-operation with CANMET. Some coal properties were determined using standard American Society for Testing and Materials (ASTM) procedures, while some non-standard techniques were used to determine minor, trace and some volatile elements, as well as dilation surface area, and mineralogical and petrographic constituents. The reactivity of the test coals was determined by low-temperature oxidation in a thermogravimetric analyser and by gasification at 900°C in a fixed-bed reactor. Duplicate analyses were performed by CANMET and the Alberta Research Council to ensure reliability of the data.

Comparison of Alberta Research Council Data with Sakata's Correlation for 50% Conversion Combustion Reaction Rate, $k(O_2)$



(Source: Kovacik, G., M. Malychuk, B. Ozum, D. E. Ungarian and A. K. Chambers, Gasification Properties of Alberta Coals, Alberta Research Council, 1989.)

Relevant tests were completed for seven Alberta coals and 14 other coals from across Canada. The results of these evaluations were compiled to produce a data bank which will serve as a reference for all Canadian coals thought to be suitable for gasification processes. Also, the data bank can be used in simulations that determine the suitability of a particular coal in a specific gasification process.

In an attempt to begin developing a model of the kinetics of char gasification, subbituminous Highvale coal and high-volatile bituminous coal from the Obed Mountain coal mine were gasified in a thermogravimetric analyser and a fixed-bed reactor. The gaseous and solid reaction products were analysed, and the reactivity of the chars was calculated from the measured product-gas and reaction-time data. Using existing "volume reaction" and "grain" models, it was possible to create a model of the gasification kinetics of the particular reaction conditions used in these experiments.

IGCC Utility Applications

While it is recognized by the power-generation industry that IGCC technology used with coal will produce minimal amounts of emissions, the technology is not yet mature; additional development of the concept is required to realize its full economic potential. Thus, it was decided an important step in promoting this technology in Canada would be a detailed economic screening study to evaluate the costs of building and operating various IGCC processes at specific locations in Canada.

The Canadian Electrical Association[1] was the lead sponsoring agency in this investigation.

Three case studies involving three coals were selected for investigation. They were:

- a nominal 250 MW IGCC unit for Nova Scotia Power Corporation at Point Aconi, using high-ash, high-sulphur, bituminous Prince coal (Case A);
- a nominal 750 MW IGCC unit for Ontario Hydro at Wesleyville, using a high-quality bituminous coal from the United States (Case B); and
- a nominal 500 MW mine-mouth IGCC unit for TransAlta Utilities Corporation, using low-rank subbituminous Blackfoot coal (Case C).

Five gasification technologies were evaluated for each of the three study cases, and some were selected for further evaluation in consultation with the host utility. The Shell technology was selected for Case A, the Texaco technology for Case B, and the Dow technology for Case C. It was stressed that as gasification technologies develop and utility needs change, the preferred technology may also change.

Performance estimates for each of the three study cases were prepared. They confirmed that all the IGCC technologies studied have high efficiencies and low emissions of NO_x, SO_x and particulates.

[1]Funding was provided by: TransAlta Utilities Corporation, Canadian Electrical Association, Nova Scotia Power Corporation, Ontario Hydro, Nova Scotia Department of Mines and Energy, Alberta Power Limited, Esso Resources Canada Limited, Ontario Ministry of Energy, Environment Canada, CANMET, and the Alberta Office of Coal Research and Technology.

In addition, the ash was converted to an inert slag which is suitable for sale as construction aggregate.

Cost estimates, project schedules and implementation plans were developed for each study case. Each implementation plan included requirements for plant staffing and construction manpower, transportation of major components, and the use of modular equipment. The specific findings of the investigation are confidential until December 13, 1991, but are available to the agencies and utility companies that participated in the study.

The investigation, which was undertaken by Bechtel Canada Inc., concluded that IGCC appears to be a technically, environmentally, and economically promising technology for near-term commercial applications.

It was further concluded that additional research and development could reduce capital costs and improve plant performance. Potential improvements in the gas turbine design, the air separation unit design, and the gasification heat recovery unit offer potential cost savings. It was recommended that additional research should include coal tests, continued review of gasification technologies, an analysis of heat recovery unit designs, emission reduction studies, evaluation of markets for by-products, and a review of developments in hot gas cleanup technology.

A Review of Potential Carbon Dioxide Separation, Disposal and Utilization Technologies

The extent to which carbon dioxide contributes to global climate change remains to be seen. In case it becomes necessary in the future to reduce the amount of carbon dioxide emitted to the atmosphere, a project was undertaken this year to review the published scientific literature on the disposal or utilization of carbon dioxide.

A study was contracted to Battelle Laboratories of Columbus, Ohio to review current and evolving technologies capable of separating, disposing or using carbon dioxide, with particular emphasis on Alberta's needs and circumstances. Under the leadership of TransAlta Utilities Corporation, the investigation was supported[1] jointly by industry and the Alberta government.

The study report provided a state-of-the-art review of appropriate technologies and approaches, and included critical assessments of the most promising options.

Essentially, the reviewed technologies were divided into four categories:

- those that avoid production of carbon dioxide;
- those that capture carbon dioxide after it has been produced;
- those that provide some means for long-term disposal of carbon dioxide; and
- those that use carbon dioxide without quickly releasing it to the atmosphere.

Altogether, approximately 30 technologies were reviewed.

Avoidance Methods

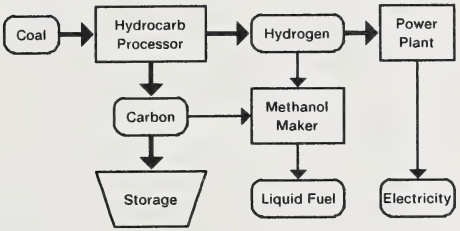
The production of carbon dioxide can be avoided by:

- not using fossil fuels;
- using less fuel to produce a given amount of energy;
- reducing the demand for energy;
- burning fossil fuels in a way that does not produce carbon dioxide; and
- burning fossil fuels so that carbon dioxide is the major constituent of flue gases.

[1]Funding was provided by a consortium led by TransAlta Utilities Corporation. The other members were: NOVA Corporation of Alberta, Edmonton Power, Shell Canada Limited, Saskatchewan Energy and Mines, Energy, Mines and Resources Canada, Environment Canada, and the Alberta Office of Coal Research and Technology.

One method for consuming coal for power production without generating carbon dioxide as a by-product has been proposed by scientists at the Brookhaven National Laboratory in New York. Called the HYDROCARB Process, it involves the hydrogasification of coal to methane which is decomposed to carbon black and hydrogen. The hydrogen so obtained can be used in many applications and produces only water when it is burned as a fuel. Some of the produced hydrogen can be reused in the HYDROCARB hydrogasification stage. Currently, this process is being tested on a pilot-plant scale.

Simplified Hydrocarb® Process Flowsheet



(Source: R&D Status of Carbon Dioxide Separation, Disposal and Utilization Technologies, Lipinsky, E. S., Battelle Laboratories 1991.)

Another carbon dioxide avoidance technique has been studied by the Argonne National Laboratory in the U.S.A. The process involves burning coal in a mixture of oxygen and recycled flue gas. This produces a flue gas with a carbon dioxide concentration of more than 90 per cent, making carbon dioxide recovery economically attractive. Independent studies have shown that plant efficiencies rivalling or surpassing those from conventional combustion processes are possible under optimal conditions. Although this approach might not be well suited for new power plants larger than 300 MW, it was claimed that for smaller new plants and retrofitted plants, flue gas recycling may be appropriate.

Capture Methods

Since most of the power plants and industrial boilers that will be operating in the year 2005 are already built, the most appropriate approach would be to find a suitable technology that can be retrofitted to the existing equipment.

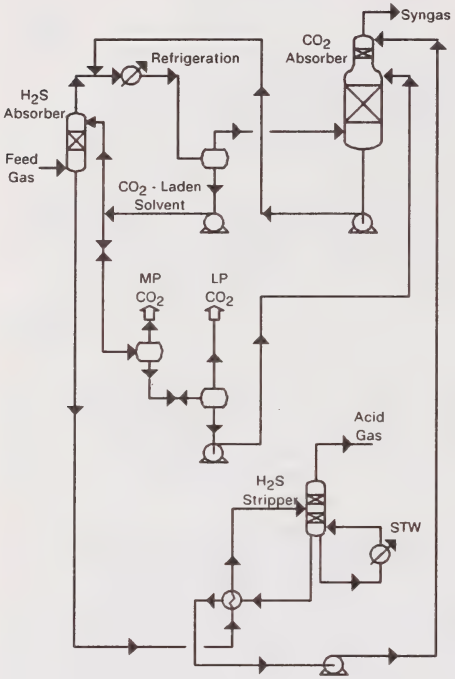
It has been demonstrated that using a class of chemicals called alkanolamines can result in recovery of carbon dioxide from flue gases. The front running technology, called Econamine FG, uses methanolamine (MEA) as the active chemical ingredient. Investigations have shown that carbon dioxide capture using this system would cost approximately $11 million a year for a 500 MW coal-fired power plant. This represents twice the cost of materials and labour associated with current requirements for emission control.

Various solvents have also been studied as potential carbon dioxide removal agents. A process called Selexol appears to depend primarily on the use of polyethylene glycol dimethyl ether, while the Sulfinol Process uses solvents based on tetrahydrothiophene dioxide. Both processes have been tested and found to be suitable for downstream treatment of emissions from Integrated Gasification Combined Cycle (IGCC) plants, but not from conventional coal combustion.

Other less-advanced technologies regarded as having some potential for success include cryogenic liquefaction, and separation techniques employing membrane technologies.

It was acknowledged that other studies have shown that the least expensive way to capture excess amounts of carbon dioxide is to use it to accelerate the growth of trees and other forms of biomass, but this investigation pointed out that this is a useful strategy so long as the biological product is not burned or allowed to decompose.

Simplified Selexol Flowsheet



(Source: R&D Status of Carbon Dioxide Separation, Disposal and Utilization Technologies, Lipinsky, E. S., Battelle Laboratories 1991.)

Carbon Dioxide Use

The Battelle study confirmed the results of other investigations, which indicated that the primary market for recovered carbon dioxide in Western Canada is enhanced oil recovery (EOR). Nonetheless, the amounts of carbon dioxide that are potentially recoverable would far exceed those required for EOR, making it necessary to find some methods for long-term disposal or use.

It was noted that the prevalence of magnesium or calcium brines in some geological formations that underlie Saskatchewan and Alberta might provide a method for converting carbon dioxide to carbonates. These chemical compounds are used in various industrial processes. Alternatively, carbonate formation could be a suitable disposal option since these compounds could remain below ground for long into the future.

Other sizeable markets for carbon dioxide might be in the construction industry, where carbon dioxide would be used as a hardening agent for cement, or in the food industry which needs liquid carbon dioxide or dry ice for cooling purposes. The latter use would provide only a temporary delay in the release of carbon dioxide to the environment.

Carbon Dioxide Disposal

In addition to the possible disposal of carbon dioxide by having it react it with brines, deep ocean disposal and underground storage were considered. It was suggested that deep ocean disposal should be approached carefully because recent studies had revealed this to be a controversial topic. Also, transporting carbon dioxide by pipeline to the west coast seemed impractical. Finally, carbon dioxide might be stored in gas-tight underground formations, an option that has been reasonably well studied in western Canada.

Subsequent Developments

Combustion and gasification research studies involving Alberta coals are continuing in Alberta and elsewhere. The IEA Annex II studies at the International Flame Research Institute have been extended, and results from this work will be reported in a forthcoming publication.

Also, a technical and economic feasibility study of building a full-scale IGCC plant in Canada is under way. The results of this investigation will be reported later, as well.

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Appendix

Research Projects Supported by Members of the Canadian Gasification R&D Steering Committee:

Project	Completion Date
Gasification of Western Canadian Coals	1987
High Temperature, High Pressure Gas Stream Cleanup	1987
Evaluation of the KRW IGCC Demonstration Stage Process for Conversion of Alberta's Highvale Coal to Electricity	1988
Economic Studies of Gasification Applications: Phase I Methanol Co-production	1988
Economic Studies of Gasification Applications: Phase II Hydrogen and Carbon Dioxide Co-production with Electricity	1988
Gasification of Canadian Coals using Pilot Plant Pressurized Gasifier	1989
Evaluation of Canadian Coals for Gasification with Texaco, BGL and Shell Technology	1989
Data Base of Canadian Coals for Gasification	1989
Evaluation of IGCC for Canadian Utility Applications	1989
Alberta Research Council Gasification R&D	1990
Pilot Plant Testing of Simultaneous Sulphur Capture During Fluid Bed Gasification	1990
Dow Gasification Evaluation	Ongoing

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Other publications in this series that deal with coal research include:

An Economic Analysis of Coal Pipeline Systems, 6 pages, January 1987. (Out of print.)

Opportunities to Use Coal in Enhanced Oil Recovery, 8 pages, April 1988.

Development of an Agglomeration Process to Beneficiate and Transport Alberta Coals, 14 pages, June 1988.

Gasification of Western Canadian Coals, 14 pages, June 1988.

Coal Research Centre, Devon, 10 pages, August 1988.

Co-processing Studies of Alberta Subbituminous Coals, 14 pages, December 1988.

Mathematical Modelling of Automedium Cyclones, 10 pages, January 1989.

The Technical Committee Approach to Coal Research, 6 pages, January 1989.

Advanced Coal Mining Techniques for Alberta, 10 pages, March 1989.

Some Combustion Studies of Alberta Coals, 13 pages, May 1989

Gasification of Alberta Coals, 10 pages, June 1989.

Development of Clean Coal Technologies for Alberta, 12 pages, July 1989.

Coal Preparation Research in Alberta, 22 pages, September 1989.

Development of a Coal-Fired Boiler for Steam Injection in Heavy Oil Recovery, 8 pages, November 1989.

Studies of Fine Coal Cleaning and Upgrading Processes for Alberta Coals, 10 pages, November 1989.

Methods for Producing Liquid Hydrocarbons from Coal, 17 pages, March 1990.

Geotechnical Studies of Overburden and Coal at Alberta Coal Mines, 14 pages, October 1990.

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Some Studies of Alberta's Coal Geology, 12 pages, January 1992.

Studies of Coal Slurry Systems and Alternative Coal Transportation Methods, 12 pages, January 1992.

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ISBN 0-86499-854-6

Pub. No. T/252

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